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Utilization of soybean deoiled cake: Functional properties and process optimization for making texturized snack using twin screw extruder

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Abstract

The effect of variation in extrusion conditions which includes feed moisture content (14-20%), screw speed (300-500 rpm), and barrel temperature (120-180 °C) on the functional properties (water absorption index (*WAI*), and water solubility index (*WSI*), fat absorption capacity (*FAC*), foaming capacity (*FC*) and sensory properties (color, appearance, flavor, overall acceptability and textural characteristics) of an expanded soybean snack was investigated. Extruded snacks were prepared by substituting maize flour with developed texturized flour of soybean at 0-40% levels. Protein content increased to 14.64% in the snacks, thus prepared with 10% texturized soybean meal as compared to that of control i.e. 7.55%. Fibre content increased while protein digestibility improved with an increased level of incorporation of texturized defatted soybean flour. Increasing feed moisture content resulted in extrudates with lower expansion, lower *WAI*, higher *WSI*, higher hardness, and lower sensory acceptability. An increase in screw speed caused a slight reduction in density and hardness of soybean extrudate. The positive influence of feed moisture on screw speed was observed whereas barrel temperature exhibited a negative influence on *WAI*. The negative coefficient of linear terms moisture and screw speed indicated that WSI decreased with an increase in these variables. Between thus higher moisture content in the extrusion process which lowered WSI values could diminish protein denaturation.

Keywords: Deoiled cake, functional, soybean, WSI, WAI, texturization, RSM

Introduction

The growing world population is 7.9 billion (Anonymous 2020a) [1] as well as that of India which is at 1.39 billion (Anonymous 2020b) [2]. Diversification of sources of cereal food from normal wheat and rice to other cereals and legumes can serve as a supplementary source of protein and calories to overcome these problems protein-energy malnutrition is the most serious problem faced by developing countries today (Bhat and Karim 2009; Boye *et al*., 2010) [7, 9]. It had been estimated that 800 million malnourished people exist in the least-developed countries (Myers 2002) [24]. The protein from the vegetable origin is an alternative to animal protein for food and cosmetics applications, due to the renewability of raw material and wide variety of sources (especially legumes, cereals and oilseeds). Soybeans, rapeseed, cottonseed, soybean seed and peanut are the most abundant protein meal and it representing 69%, 12.4%, 6.9%, 5.3% and 2.8% of world protein meal production respectively (Ash and Dohlman 2006) [6]. Vegetable proteins are mostly deficient in sulfur amino acids as compared to animal proteins and also contain antinutritive factors. These limitations can easily be overcome by supplementation with other proteins and Physico-chemical treatments. Besides oilseed protein makes a significant contribution to human dietary protein intake. Purification of vegetable protein involves physicochemical and thermal processing which affects the nutritional value of the final products, as well as the functional properties of interest when the proteomic product is destined for food or non-food purposes. When added to foods, protein confers desirable functional properties, such as whipping capacity, viscosity, emulsification, and water and oil holding capacities. Proteins play a decisive role in the nutritional, sensory, physicochemical and organoleptic properties. The protein content of defatted meals from dehulled oilseeds depends on the seed and ranges between 35% and 60% (d.b.).

Due to their nutritional values and high protein content, soybean plays a significant role in the manufacturing of texturized snacks. However, very little information is available on the incorporation of texturized defatted flour in making a texturized snack. Keeping these points in mind, the present study was planned with the objectives to optimize and to find out the best level of texturization based on quality, to find the overall acceptability of the snacks based on sensory evaluation by panelists and to study the textural, functional and color properties of snacks prepared after incorporation of texturized defatted flour of soybean.

Materials and Methods

Raw materials

Soybean and maize were procured from the Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana.

Oil extraction

Soybean was cleaned and defatted using a laboratory oil expeller. The meal was dried, milled into grits using Super Mill (Perten Instruments, Sweeden). After that, the sample was sieved using a mesh screen to separate out the large particles of the seed coat. A similar procedure was followed for maize.

Extrusion process for soybean

Texturization of soybean was carried out by using Clextral *BC*-21 twin-screw extruder (Clextral, Firminy, France). The operating conditions were (14-20%) feed moisture, (300-500 rpm) screw speed, and (120-180 °C) barrel temperature selected based on preliminary trials. Texturized proteins were milled into flour using a cyclotec mill (Newport Scientific, Australia) and packed in suitable packaging material for further study.

Experimental design

Central composite rotatable design (*CCRD*) of response surface methodology (RSM) was used to optimize the process. Extrusion process independent variables (feed moisture content, screw speed, and temperature) were coded to the level of -1, 0, +1 such that one factor at a time of experimental design (Myers 1971). The levels of each variable were obtained by preliminary trials. Dependent variables were *WA*, *WSI*, *FAC*, *FC*, and *PDI*. The independent variables included the moisture content (14-20%), screw speed (300-500 rpm), and barrel temperature (120-180 °C). Twenty experimental runs were carried out by using the same design. The main advantage of *RSM* was that it reduced the number of experimental runs needed to provide sufficient information for statistically acceptable results. The results were analyzed by the multiple linear regression method which describes the effects of variables in the models derived. Experimental data were fitted to the selected models and regression coefficients were obtained. The analysis of variance (*ANOVA*) tables was generated for each of the response functions. The individual effect of each variable and also the effects of the interaction term in coded levels of variables were determined. Out of 20 solutions, 14 solutions were found suitable for numerical optimization. Numerical optimization provided nine solutions with desirability values varying from 0.81 to 0.82. Range of predicted values of SME (2.44-2.51), expansion ratio (1.25-1.26), true density (0.461-0.463), and PDI (21.51-22.02) were used to overlay plot graphical optimization. Best extrusion conditions were 18.51 to 19.01% moisture, 499.91-500.00 rpm screw speed, and 179.98-180ºC barrel temperature. Texturized soybean defatted meal was prepared using the above-optimized conditions. The best level of texturized defatted soybean meal (10, 20, 30, and 40%) incorporation was selected based on functional, color, hardness, and sensory score.

Extrudate properties: Extrudates obtained after the extrusion process studied for the following properties will be studied.

Specific mechanical energy (SME): SME is calculated by using the method outlined by Sokhey *et al*. (1994) [32].

Expansion ratio (ER): ER calculated by using the procedure mentioned by Kollengode *et al*. (1996) [18].

True density (TD): TD calculated by using the method of Egan *et al*. (1981) [13].

Product responses

Water absorption index (WAI), Water solubility index (WSI), and Fat absorption capacities (FAC)

WAI was measured according to Stojceska *et al*. (2009) [34]. A similar method was used to measure FAC, although a 0.5 g sample was used in this case (Lin *et al*., 1974) [31].

$$\text{WAI (g/g)} = \frac{\text{Weight of residue}}{\text{ry weight of residue}};\quad \text{WSI (\%)} = \frac{\text{Weight of dry matter in supernatan}}{\text{Dry weight of sample}} \times 100$$

$$\text{FAC (\%)} = \frac{\text{Weight of fat absorbed by sample}}{\text{Dry weight of sample}} \times 100$$

Foaming capacity (FC)

FC was determined according to the method (Kabirullah and Wills 1983) [15].

Bulk density (BD)

The Bulk densities (g per ml) of defatted flour were determined by the volumetric method (Pan *et al*., 1998) [26].

$$\text{Foaming capacity (\%)} = \frac{\text{Foam volume after 30 min}}{\text{Initial foam volume}} \times 100 \quad \text{BD (g/cc)} = \frac{\textit{Weight of sample}}{\textit{Volume displaced by sample}}$$

Protein digestibility (PD)

The *in vitro* protein digestibility was estimated using the method (Akeson and Stachman 1964) [4]. The residue left was then analyzed for Nitrogen content by the Micro-Kjeldahl method. The digestibility coefficient was determined by subtracting the residual protein from the initial protein based on 100 gm of the sample.

Chemical analysis

Chemical characteristics of raw materials, defatted meals, and snacks were analyzed using standards procedures (AACC 2000) [3].

Snacks preparation

Extruded snacks were prepared after incorporation of texturized defatted soybean meal (at 10, 20, 30, and 40% levels) in maize flour.

Color analysis of extruded snacks

Color of snack samples was evaluated by measuring the *L* (100: white; 0: black), *a* (+, red; -, green), and *b* (+, yellow; -, blue) value using a Minolta Spectrophotometer CM-508d (Minolta Co., Ltd Japan) (Kimura *et al*., 1993) [16].

Texture analysis of extruded snacks (Hardness)

The texture of the extruded snacks was evaluated on a texture analyzer (TA-XT2i) (Bourne 1982). Extruded snacks were subjected to a compression test to measure hardness (N). The settings used for the test were pretest speed (1mm/s), test speed (1mm/s), post-test speed (1mm/s), distance (15mm), and force (60g).

Sensory evaluation of extruded snacks

Sensory evaluation of extruded snacks was carried out by a semi-trained panel for color, appearance, texture, flavor, mouthfeel, and overall acceptability using a 9-point hedonic scale (Larmond, 1970) [20].

Statistical analysis

Data obtained were analyzed statistically using techniques of analysis of variance (ANOVA) by CPCS Software (developed by Punjab Agricultural University, Ludhiana, India) at a 5% level of significance (Singh *et al*., 1991) [31].

Results and Discussion

Preparation of texturized defatted soybean meal

During the process of preparation of texturized soy snack from soybean meal obtained after oil extraction, it was observed that higher SME usually resulted in a greater degree of starch gelatinization of the meal and extrudate expansion. Screw speed and barrel temperature were significant model terms. The specific mechanical energy of soybean extrudate ranged from 2.06 to 4.95 Wh/kg. Regression analysis showed that SME decreased with an increase in moisture content. Higher moisture produced a lubricating effect, resulting in less energy use subsequently reduced SME. SME lowered with higher temperature while increased with increase in screw speed. An increase in screw speed increased the SME as the screw delivers more energy because it delivers a higher screw shear rate which leads to an increase in SME. The regression model for SME, expansion ratio, true density, and protein digestibility was highly significant (p<0.0001), with a high correlation coefficient (R^2 = 0.95, 0.97, 0.91, and 0.94 respectively) (Table 2). None of the models showed a significant lack of fit (p>0.01), indicating that all the second-order polynomial models correlated well with the measured data. The predicted R square was found in reasonable agreement with the adjusted R square for all the parameters. For all the parameters adequate precision should be greater than 4 which is desirable.

The expansion ratio for soybean meal extrudates varied between 1.08-1.28 whereas true density of extrudate varied between 0.485-0.730 g/cm^3. A higher expansion ratio for soybean meal was obtained at low feed moisture and higher barrel temperature. The F value of 42.00 implied that the model was significant. Values of "Prob > F" less than 0.05 indicated that model terms were significant. Feed moisture, screw speed, barrel temperature, and interaction of feed moisture with screw were significant model terms. Values greater than 0.1 indicated that model terms were not significant. The "Lack of Fit F value" of 1.67 implied that the lack of fit was not significant relative to the pure error. The expansion ratio increased significantly with a decrease in feed moisture and an increase in barrel temperature. Feed moisture is the main factor affecting extrudate density and expansion (Ilo *et al*., 1999). Increased feed moisture leads to a sharp decrease in the expansion of extrudate.

For true density, the model F value of 11.70 implied that the model was significant. Values of "Prob > F" less than 0.05 indicated that model terms were significant. Screw speed and barrel temperature were significant model terms. Values greater than 0.1 indicated that the model terms were not significant. The "Lack of Fit F value" of 0.35 implied that the lack of fit was not significant relative to the pure error. True density decreased with an increase in feed moisture and barrel temperature while it increased with an increase in screw speed.

For the protein digestibility index, the model F value of 26.84 implied that the model was significant. Values of "Prob > F" less than 0.05 indicated that model terms were significant. Feed moisture, screw speed, barrel temperature, and interaction of feed moisture with screw speed were significant model terms. Values greater than 0.1 indicated that the model terms were not significant. The "Lack of Fit F-value" of 1.77 implied that the lack of fit was not significant relative to the pure error. PDI for extrudates of soybean meal ranged from 19.47-27.87%. PDI increased with decreased feed moisture and increased screw speed and barrel temperature. PDI is an indication of the amount of water-dispersible protein present in the sample. For PDI, the interaction between moisture and screw speed; moisture and barrel temperature; and screw speed and barrel temperature varied significantly.

Numerical optimization provided nine solutions with desirability values varying from 0.81 to 0.82. Range of predicted values of SME (2.44-2.51), expansion ratio (1.25-1.26), true density (0.461-0.463), and PDI (21.51-22.02) were used to overlay plot graphical optimization. Best extrusion conditions were 18.51 to 19.01% moisture, 499.91-500.00 rpm screw speed, and 179.98-180 °C barrel temperature. Texturized soybean defatted meal was prepared using the above-optimized conditions.

Characteristics of defatted soybean meal and maize meal

The defatted soybean meal had 2.7% moisture, 2.3% fat, 52.9% protein, 3.3% fiber, and 56.3% protein digestibility. Maize had 12.33% moisture, 4.14% fat, 10.43% protein, 1.12% ash and 35.87% protein digestibility.

Functional properties

Water absorption index (WAI)

The WAI measures the amount of water absorbed by protein, starch, and other molecules and can be used as an index of gelatinization (Anderson *et al*., 1969) [5]. WAI depends on the availability of hydrophilic groups that bind water molecules. WAI for texturized defatted soybean meal ranged from 2.127-3.35g/g (Table 1). WAI increased with an increase in feed moisture and screw speed while decreased with barrel temperature. The amount of water associated with proteins was closely related to specific amino acids profile and increased with the number of charged groups (Kuntz and Kauzmann 1974) [19], conformation, hydrophobicity, pH, temperature, ionic strength, and protein concentration (Damodaran 1997) [10].

The value of R^2 is found to be 0.90. P-value (0.62) for Lack of fit implies that it was not significant (Table 2). Regression analysis results showed that barrel temperature had a significant negative linear effect whereas moisture and screw speed had a positive linear (p<0.001) effect and significant quadratic effect on WAI (Table 3).

Water solubility index (WSI)

WSI is used as an indicator of the degradation of molecular components (Kirby *et al*., 1988). WSI for texturized defatted soybean meal ranged from 2.22-5.26% (Table 1). Regression model fitted to experimental results. 1.34 P-value of Lack of fit implies that it was not significant. The value of R^2 was found to be 0.99 (Table 2). Regression analysis showed a significant positive linear influence of moisture and screw speed, while the negative influence of barrel temperature ($p<0.05$) (Table 3). The significant negative influence of barrel temperature was observed while the positive influence of screw speed and feed moisture content on WSI of a texturized defatted meal of soybean was recorded. There was a significant quadratic terms effect ($p<0.01$) of moisture content and temperature on WSI. Also, a significant interaction of moisture and temperature ($p<0.01$) was recorded on WSI. It was observed from regressions analysis that during extrusion-cooking, higher moisture contents increase the WSI of protein flour. The high mechanical shear caused the breakdown of macromolecules to small molecules with higher solubility. The increasing temperature would result in degradation of molecule increasing WSI (Ding *et al*., 2005) [12].

Fat absorption capacity (FAC)

Defatting increased protein solubility, water, and oil absorption capacity of oil. The capacity of the protein to absorb water and oil is determined by its polar and nonpolar amino acids composition, respectively. FAC for texturized defatted soybean meal ranged from 54.59-77.28% (Table 1). P-value (0.32) for Lack of fit implies that it was not significant. The value of R^2 was found to be 0.99 (Table 2). Regression analysis results (Table 3) showed the significant negative influence of moisture, screw speed, and temperature ($p<0.05$) was recorded. There were significant quadratic terms effects ($p<0.01$) of moisture content and temperature on FAC. Reported on significant interaction of feed moisture with screw speed, feed moisture with temperature, and screw speed with temperature ($p<0.01$) on FAC are also available. Feed moisture, screw speed, barrel temperature, and their interactions were significant model terms. FAC decreased with an increase in feed moisture, screw speed, and barrel temperature.

It was observed from regressions analysis that during extrusion-cooking, higher moisture contents decrease FAC of protein flour. Defatting increases the protein solubility and water and oil absorption capacities of the meals. The capacity of the protein to absorb water and oil is determined by its polar and non-polar amino acids composition, respectively (Sathe and Salunkhe 1981) [28]. FAC of the flaxseed protein concentrate was higher than that of amaranth protein concentrate (De Luquez *et al*., 1997) [11].

Foaming capacity (FC)

The foaming capacity for texturized defatted soybean meal ranged from 10.14-22.65% (Table 1). The regression model fitted to experimental results of foaming capacity is presented in Table 2. The value of R^2 is found to be 0.99 (Table 2). Interaction ($p<0.05$) of all independent variables was found significant. Regression analyses indicate that foaming capacity decreases with an increase in barrel temperature and increases with an increase with feed moisture and screw speed. The analysis of variance (ANOVA) for foaming capacity of the quadratic model is given in Table 3.

Water absorption index, foaming capacity and protein digestibility increased with an increased level of incorporation of texturized defatted flour soybean in maize flour for extruded snacks making hence increasing protein content leading to improved functional properties Table 4).

Numerical optimization provided nine solutions with desirability values varying from 0.61 to 0.72. Range of predicted values of WAI (2.88-3.16), WSI (3.14-3.57), FAC (58.03-68.88), and foaming capacity (14.12-22.59) was used to overlay plot graphical optimization.

Best extrusion conditions for functional soybean meal were 19.84% feed moisture, 300 rpm screw speed, and 180°C barrel temperature with responses 2.89 g/g WAI, 3.58 percent WSI, 63.48 percent FAC and 18.86% foaming capacity with 0.72 of desirability. Texturized functional soybean defatted meal was prepared using the above-optimized conditions.

Snacks Characteristics

The moisture content of snacks incorporated with defatted soybean meal (at 10, 20, 30, and 40% level) is 4.32%, 4.51%, 4.62%, and 5.08%, respectively as compared to that of control (4.79%). Protein, fibre, and ash content increased while protein digestibility improved with an increased level of incorporation of texturized defatted soybean flour in extruded snack making. Protein content was maximum in extruded snacks prepared with 40% texturized soybean meal (Table 4).

Functional properties of snacks

Functional properties improved because protein content increased with an increased level of texturized defatted flour of soybean as these were rich in proteins (Table 4). Sudha *et al*. (1998) [35] showed functional properties were lowered with an increase in the level of finger millet flour as protein content decreased in the blend but the reverse was the case in the present study. But in cases, since the texturized protein was added. So functional properties improved except for FAC and WSI. WAI, FC, and PD increased with an increased level of incorporation of texturized defatted soybean flour with maize flour for snack making. FAC decreased with an increased level of incorporation of texturized defatted soybean flour in maize flour for snack making. It has been reported that protein content had an inverse correlation with the free lipid level of instant noodles (Moss *et al*., 1987; Park and Baik, 2004) [22, 27]. Therefore it is expected that snacks made from protein-rich texturized defatted soybean flour will absorb less fat as compared to controls.

Color measurements of extruded snacks

There was a decrease in L values for texturized defatted soybean snacks from 73.54 to 62.58 (Table 5). A linear decrease in ‘L’ values and an increase in a and b values as the defatted texturized flour of soybean increased for snacks preparation has been observed. The decreasing L and increasing a and b values lead to the darkening of biscuits when they supplemented Virgin coconut meal in biscuits (Srivastava *et al*., 2010) [33]. The decline in L values signifies that with an increase in percentage incorporation the lightness decreased, while a and b values show an increase in redness and yellowness in extruded snacks. A similar trend was observed by scientists (Srivastava *et al*., 2010; Singh *et al*., 1996) [33, 30]. Thus observed results in this study followed similar trends. The color development is contributed by the Maillard reaction that results in brown color (Singh *et al*., 1993) [29]. It was reported that with an increase in protein content there is a decrease in L value (Gallagher *et al*., 2005) [14]. In the snacks, a significant difference was observed for all L, a, and b values.

Textural properties of extruded snacks

The average peak force is a measure of extruded snacks hardness. An increasing trend was observed for the hardness of extruded snacks prepared from texturized defatted soybean flour. Both hardness and rupture energy increased from 67.51 to 181.94 N and 88.86 to 218.12Nmm, respectively for extruded snacks (Table 5). Thus, with an increase in defatted soybean flour for extruded snacks making hardness and rupture energy appear to increase linearly. Hardness increased due presence of more proteins at higher enrichment levels which lower down expansion ratio of extruded snacks. Protein content had an inverse relation with expansion and linear relation with bulk density. As protein content has an inverse relation with expansion ratio, so less puffing of extruded snacks was there and they requiring more force to break down. This showed that incorporation of texturized defatted soybean flour had negative results on textural properties.

Sensory evaluation of extruded snacks

Statistical analysis showed that there was a significant difference in color, appearance, texture, flavor, mouthfeel, and overall acceptability of extruded snacks as compared to those of control. Overall acceptability scores for extruded snacks incorporated with texturized defatted soybean flour ranged from 8.05-6.36 (Table 5). Extruded snacks made from 20% texturized defatted soybean were given maximum overall acceptability scores as compared to higher levels. It is reported that cookies made from deoiled maize flour were acceptable up to 15% by a consumer (Nasir *et al*., 2010) [25].

Table 1: Effect of texturization conditions on dependent variables

Sr. No.	Extrusion parameters			Responses			Functional properties				
	Moisture content (%)	**Screw speed (rpm)**	**Barrel Temp (°C)**	**SME**	**ER**	**TD**	**Water absorption index (g/g)**	**Water Solubility index (%)**	**Fat Absorption capacity (%)**	**Foaming capacity (%)**	**Protein Digestibility index (%)**
1	14.00	300.0	120.0	4.501	1.18	0.681	2.127±0.031	2.753±0.050	65.790±0.036	13.107±0.051	23.915±0.030
2	20.00	300.0	120.0	4.493	1.08	0.659	2.773±0.557	4.097±0.078	77.280±0.020	14.150±0.132	21.492±0.167
3	14.00	500.0	120.0	4.869	1.21	0.620	3.153±0.015	3.247±0.032	69.460±0.036	22.657±0.055	21.529±0.061
4	20.00	500.0	120.0	4.804	1.113	0.619	3.360±0.040	4.440±0.036	71.707±0.015	16.237±0.035	28.627±0.025
5	14.00	300.0	180.0	2.06	1.26	0.526	2.767±0.035	2.520±0.026	68.233±0.035	10.267±0.038	10.643±0.056
6	20.00	300.0	180.0	2.177	1.18	0.503	2.870±0.020	3.660±0.017	63.760±0.036	19.143±0.060	15.583±0.032
7	14.00	500.0	180.0	2.551	1.272	0.491	3.070±0.026	2.877±0.021	69.447±0.057	12.247±0.047	14.733±0.375
8	20.00	500.0	180.0	2.441	1.247	0.445	2.637±0.035	3.430±0.026	54.597±0.025	13.213±0.025	21.751±0.032
9	17.00	400.0	150.00	3.021	1.169	0.517	2.937±0.040	4.913±0.032	58.693±0.015	20.620±0.026	18.644±0.031
10	17.00	400.0	150.0	3.115	1.193	0.510	2.727±0.031	4.920±0.050	58.747±0.015	21.300±0.020	20.144±0.022
11	17.00	400.0	150.0	3.015	1.2	0.489	3.093±0.051	4.747±0.015	58.733±0.076	20.887±0.032	21.130±0.030
12	17.00	400.0	150.0	2.61	1.19	0.586	2.783±0.035	4.857±0.021	58.213±0.032	21.800±0.036	21.188±0.038
13	17.00	400.0	150.0	3.105	1.19	0.491	2.850±0.030	4.907±0.045	58.553±0.067	20.357±0.051	21.172±0.026
14	17.00	400.0	150.0	2.951	1.19	0.485	2.833±0.031	4.797±0.025	58.390±0.036	20.697±0.025	21.216±0.073
15	11.95	400.0	150.0	4.147	1.21	0.537	2.667±0.035	3.493±0.042	67.287±0.042	14.550±0.036	15.590±0.026
16	22.05	400.0	150.0	4.576	1.11	0.486	2.777±0.025	5.260±0.026	65.343±0.025	15.493±0.112	21.383±0.016
17	17.00	231.8.	150.0	2.586	1.161	0.540	2.797±0.025	3.143±0.040	69.667±0.061	17.313±0.032	16.407±0.021
18	17.00	568.2.	150.0	3.286	1.25	0.486	3.353±0.042	3.620±0.026	65.687±0.038	21.137±0.040	24.112±0.043
19	17.00	400.0	99.54	4.946	1.14	0.730	3.233±0.021	2.923±0.025	72.460±0.053	14.233±0.252	26.183±0.087
20	17.00	400.0	200.4	2.277	1.28	0.546	2.957±0.047	2.220±0.030	60.893±0.051	10.137±0.078	14.345±0.028

Table 2: Analysis of variance for the fit of experimental data to response surface model

Regression	Sum of Squares							
	Product responses				**Functional properties**			
	SME	**ER**	**TD**	**PDI**	**WAI**	**WSI**	**FAC**	**FC**
R square	0.9552	0.9742	0.9133	0.9407	0.9021	0.9964	0.9957	0.9939
Adjusted R square	0.9150	0.9510	0.8353	0.9133	0.8139	0.9932	0.9985	0.9884
Lack of fit	3.69	1.67	0.35	1.77	0.6200	1.3400*	0.3200*	0.8660*
Adequate precision	16.631	24.817	13.657	18.562	13.2780	55.4220	134.8700	41.2800
CV (%)	8.64	1.01	5.69	5.99	4.2000	2.0500	0.3700	2.9100

* Significant at $p<0.001$

Table 3: Regression coefficients for fitted models

Factors	Regression coefficients							
	Product responses				**Functional properties**			
	SME	**ER**	**TD**	**PDI (%)**	**WAI (g/g)**	**WSI (%)**	**FAC (%)**	**Foaming capacity**
Intercept of Model	2.980**	1.19**	0.5100*	20.57**	2.860**	14.86**	58.53**	20.94**
A: Moisture content (MC)	0.048	-0.034**	-0.0130*	1.93**	0.083*	0.52**	-0.65**	0.42**
B: Screw speed (SSp)	0.190	0.021**	-0.012*	2.07**	0.170**	0.14**	-1.22**	1.04**
C: Barrel temperature (BT)	-1.020**	0.045**	-0.068**	-3.86**	-0.062**	-0.24**	-3.50**	-1.31**
AB (MC x SSp)	-0.035	0.007	-0.0002*	1.41*	-0.170**	-0.08*	-2.45**	-1.88**
AC (MC x BT)	0.010	0.011	0.0058	0.89*	-0.180**	-0.08**	-4.12**	1.91**
BC (SSp x BT)	0.009	0.002	0.0010	0.73*	-0.140**	-0.09**	-.076**	-1.94**

A^2 (Moisture content)^2	0.450*	-0.010	0.0020	-0.70*	-0.073*	-0.17**	2.78**	-2.10**
B^2 (Screw speed)^2	-0.052	0.006	0.0024	-0.08*	0.057*	-0.53**	3.26**	-0.62**
C^2 (Barrel temperature)^2	0.190*	0.008	0.0470*	-0.07*	0.059*	-0.83**	2.90**	-3.15**

*Significant at $p<0.005$

** Significant at $p<0.001$

Table 4 Chemical characteristic and functional properties of snacks prepared from texturized defatted meal of soybean

Sample	%	Chemical composition					Functional Properties				
		Moisture (%) ±SD	**Protein (%) ±SD**	**Fat (%) ±SD**	**Fibre (%) ±SD**	**Ash (%) ±SD**	**WAI (g/g) ±SD**	**WSI (%) ±SD**	**FAC (%) ±SD**	**FC (%) ±SD**	**PD (%) ±SD**
Control	0	4.79±0.02	10.55±0.03	0.12±0.02	2.16±0.03	0.73±0.02	2.72±0.02	4.59±0.08	170.57±0.22	7.79±0.01	39.30±0.72
Soybean	10	4.32±0.03	14.64±0.01	1.78±0.06	7.38±0.01	0.82±0.02	4.39±0.02	5.13±0.03	128.70±0.11	11.30±0.25	81.66±1.17
	20	4.51±0.03	18.87±0.02	2.24±0.01	11.19±0.04	0.96±0.01	4.68±0.01	4.67±0.06	119.86±0.20	14.62±0.03	82.79±.33
	30	4.62±0.04	23.11±0.03	4.23±0.02	15.07±0.03	1.15±0.04	5.20±0.04	4.32±0.02	120.51±0.55	16.38±0.03	84.22±1.65
	40	5.08±0.06	27.34±0.01	4.49±0.02	18.71±0.02	1.40±0.01	5.85±0.03	2.36±0.05	108.41±0.29	20.270.02	86.23±1.17
					LSD (p<0.05)		0.047	0.076	0.9903	0.090	2.262

SD: Standard deviation; LSD: Least significant difference

Table 5: Effect of incorporation of texturized defatted meal on texturization on the color (L, a, b values) and sensory evaluation of snacks

Sample	Percent	Color properties			Textural properties			Sensory properties		
		L±SD	**a ±SD**	**b ±SD**	**Hardness (N) ±SD**	***RE (Nmm) ±SD**	**Color**	**Appearance**	**Texture**	**Overall acceptability**
Control	0	41.713±0.310	1.003±0.131	10.427±0.055	82.34±2.86	108.09±1.86	8.09	8.20	8.59	8.17
Soybean	10	73.540±1.093	0.813±0.194	13.747±0.489	67.51±17.88	88.86±17.42	8.30	8.50	8.2	8.05
	20	72.097±2.187	1.427±0.083	15.637±1.199	161.79±4.27	170.38±1.76	8.49	8.50	8.60	8.53
	30	64.280±1.685	1.730±0.095	16.187±0.441	172.88±2.21	183.03±2.87	8.20	8.20	8.00	7.41
	40	62.583±1.053	1.987±0.372	19.517±0.904	181.94±3.03	218.12±6.28	7.60	7.70	7.20	6.36
LSD (p<0.05)		3.927	0.404	1.786	14.743	17.834	0.182	0.170	0.180	0.268

*RE: Rupture energy

SD: Standard deviation; LSD: Least significant difference

Conclusion

The addition of texturized defatted soybean flour in extruded snacks making resulted in significant improvement in crude protein, crude fibre, ash, and protein digestibility of extruded snacks. It could be concluded that although extruded snacks with 40% levels of texturized defatted soybean flour were nutritionally rich but received lower scores for different organoleptic attributes. The textural properties showed that hardness and rupture energy increased with an increased level of texturized defatted soybean flour for extruded snack making. Incorporation of texturized defatted soybean flour had a significant effect on the color value, lightness decreased while *a* and *b* increased producing darker color with increased levels of supplementation. As for increasing the amount of texturized defatted soybean flour for extruded snacks making functional properties like water absorption index, foaming capacity and protein digestibility increased proportionally but fat absorption capacity and water solubility index decreased proportionally. Thus extruded snacks were acceptable for all attributes evaluated up to 20% while higher levels had negative effects. The study demonstrated that deoiled cake a byproduct obtained from the soybean oil industry offers great potential for supplementation of proteins in food products. These would be beneficial for an industry that adding oilseed protein to extruded snacks improved their liking and acceptability, while also improving the nutritional content.

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